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Variation in Gravity Droop Due to Gun Elevation: A Small but Predictable Source of Aiming Inaccuracy

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13. ABSTRACT *(Maximum 200 words)*

When a gun is elevated or depressed from horizontal, the component of gravity perpendicular to the gun axis is diminished, resulting in a decreased gravity-induced droop of the muzzle angle. The fire control algorithm for the M1A1 tank does not take this change in "gravity droop" into account when it computes the gun elevation required to engage a distant target. We show that this source of aiming inaccuracy is small, but easily predictable, and hence correctable.

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1. INTRODUCTION

In 1984, the U.S. Army began a program to identify and reduce, if possible, sources of tank gun inaccuracies (error). Not surprisingly, as this program progressed, the magnitude of reported error sources decreased. For example, a retrospection of the program review for the year 1987 (Schmidt 1987) shows that topics of discussion then included the following: tube-to-tube variability and the effects of fleet zero; temperature-dependent jump; and thermal jacket design. The variation in fall-of-shot associated with these subjects ranges from several tenths of a mil (6,400 mils = one revolution) to 1 or more mils. On the other hand, a sampling of recent studies shows that the discussion of error sources has diminished by almost an order of magnitude (e.g., see Held, Webb, and Schmidt [to be published]).

This report documents yet another small error source — variation in gravity droop with gun elevation — an effect that is typically less than 0.1 mil in magnitude for the M1A1 tank gun. Unlike many sources of error, however, this inaccuracy is easily predictable and, therefore, could be eliminated by a simple correction to the fire control algorithm.

2. ANALYSIS

If the gun is mechanically elevated from horizontal to an angle α, the current fire control algorithm assumes the muzzle pointing angle, θ, see Figure 1, has changed by precisely α. However, the gravity-induced curvature also changes as the gun elevates. This will impart an additional muzzle angle change, $\beta(\alpha)$, so that the new muzzle pointing angle is actually:

$$\theta(\alpha) = \theta(\alpha{=}0) + \alpha + \beta(\alpha) \quad . \tag{1}$$

The correction, β, is small, $\frac{\beta(\alpha)}{\alpha} \approx O(10^{-5})$; nevertheless, it is very predictable.

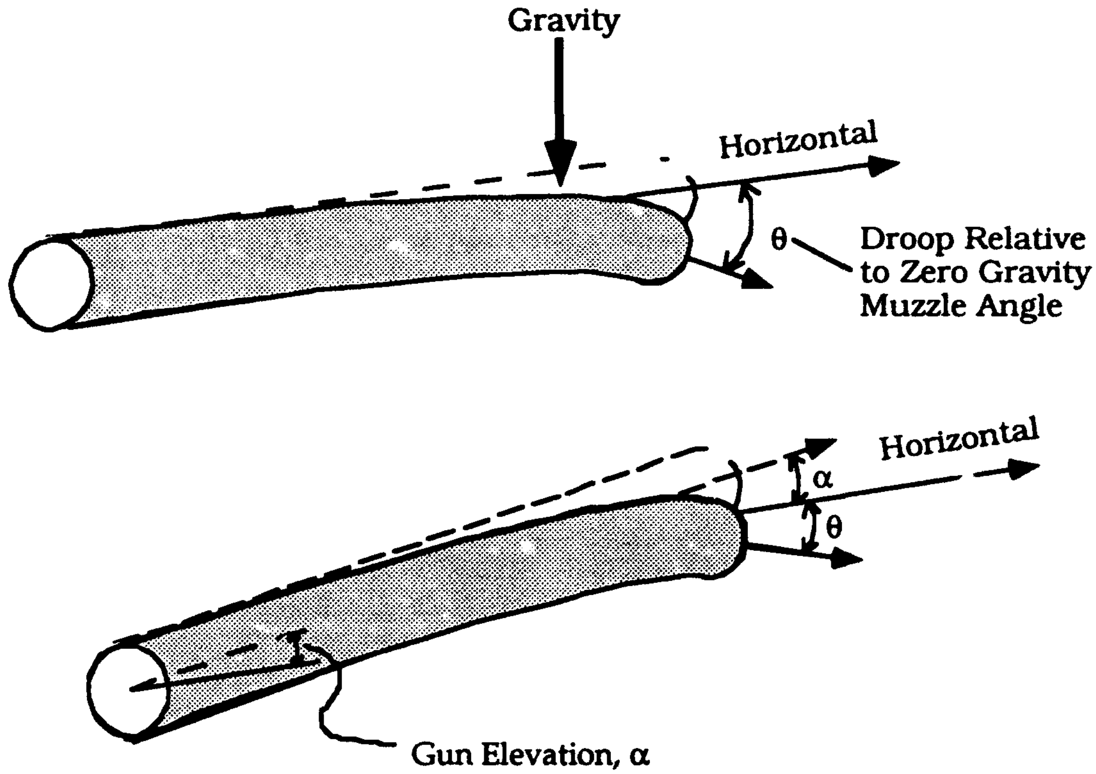

Figure 1. Illustrating the effect of gravity on muzzle angle, θ.

To describe the problem, we will first need to specify/define several terms. We will consider the gun barrel to be supported at two points. The barrel will be at zero elevation, $\alpha = 0$, if a line drawn between the two supports is horizontal relative to the (vertical) earth's gravitational field. If there were no gravity, or inherent tube curvature, the muzzle pointing angle would be zero when the gun elevation was zero. However, following the treatment given in Bundy (1993), we can show that the muzzle pointing angle when the gun elevation is zero and the acceleration due to gravity is g will be given by:

$$\theta(\alpha=0) = -C|g| , \qquad (2)$$

where C is a constant which depends on the gun barrel geometry, material properties, and location of the support points. The minus sign indicates that the muzzle angle due to gravity droop is below horizontal at zero elevation. Rather than derive the expression for C here, we will simply use the result given in Bundy (1993) for the muzzle pointing angle when the barrel is at the ambient temperature of 21° C, viz.:

$$\theta(\alpha{=}0) \;=\; -\,0.82\ \text{mil} \quad . \tag{3}$$

(Note, it was shown in Bundy [1993] that the change in gravity droop with a change in temperature of the barrel, from firing, is very small, less than 2% from ambient, for any reasonable barrel temperature change, i.e., firing scenario.) From Equations 2 and 3, we find, for $|g| = 9.8\ \text{m/s}^2$,

$$C \;=\; 0.084\,\frac{\text{mil}\cdot\text{s}^2}{\text{m}} \quad . \tag{4}$$

When the gun is elevated by an angle α, the muzzle pointing angle will be:

$$\theta(\alpha) \;=\; \alpha \;-\; C\,g\cos(\alpha) \quad . \tag{5}$$

Thus, from Equations 1, 2, 3, and 5, the gravity droop correction to the muzzle pointing angle will be:

$$\beta \;=\; \theta(\alpha) - \theta(\alpha{=}0) - \alpha \;=\; C|g|\{1-\cos(\alpha)\} \;=\; 0.82\,\{1-\cos(\alpha)\}\ \text{mil} \quad . \tag{6}$$

From Equation 6,

$$\frac{\beta(\alpha)}{\alpha} \;=\; \frac{0.82\,\{1-\cos(\alpha)\}}{\alpha} \quad , \tag{7}$$

where it is assumed that α will be expressed in mils. For α = 172 mils ($\cong$ 10°), for example,

$$\frac{\beta(\alpha)}{\alpha} \;=\; 7.2\times 10^{-5} \quad . \tag{7}$$

When the M1A1 tank is on flat level ground, mechanical constraints between the gun and the hull limit the range of α from -172 mil (-10°) to +344 mil (+20°) (Hoffman 1987). However, if the hull were pitched up or down, in a mountainous terrain for example, the range of α may exceed these limits. We have plotted β vs. α in Figure 2 and tabulated the comparison in Table 1. As shown, the correction β is less

than 0.003 mil when α is less than 86 mils (5°), but it exceeds 0.028 mil when α is greater than 258 mils (15°).

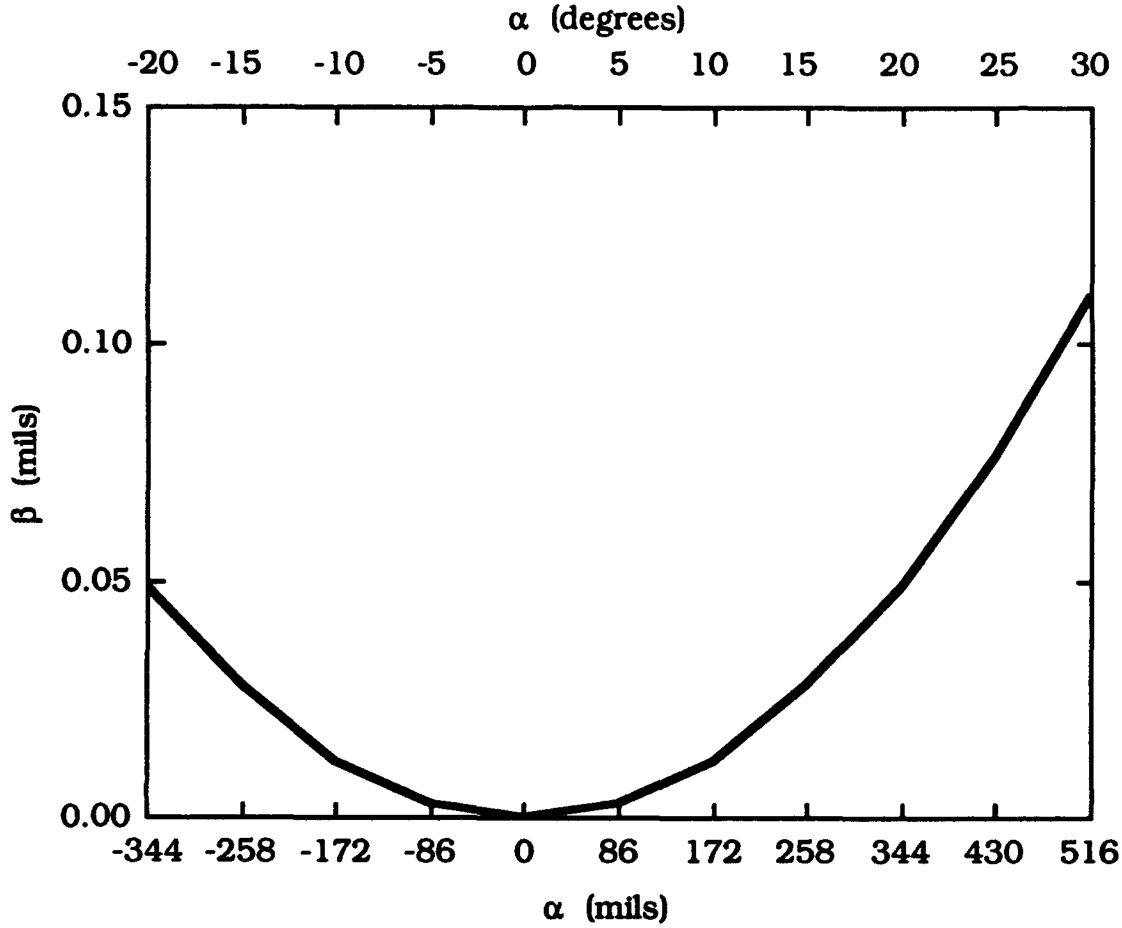

Figure 2. Correction factor, β, vs. α.

Table 1. Correction Factor, β, vs. α

$\lvert\alpha\rvert$ (mils)	$\lvert\alpha\rvert$ (degrees)	β (mils)
86	5	0.003
172	10	0.012
258	15	0.028
344	20	0.049
430	25	0.076
516	30	0.110

3. CONCLUSIONS AND RECOMMENDATIONS

When elevation or depression of the M1A1 tank gun barrel is less than 86 mils (5°) in magnitude, the correction in the muzzle pointing angle due to a change in gravity droop with elevation is negligible, less than 0.003 mil. However, if the change in elevation or depression exceeds 258 mils (15°) in magnitude, the change in muzzle pointing angle due to the change in gravity droop is about ten times larger, exceeding 0.028 mil.

The muzzle pointing angle can be compensated/corrected for the change in gravity droop with elevation by adding $\beta = 0.82\,\{1 - \cos(\alpha)\}$ mil to the elevation angle, α.

Situations where the tank gun may be elevated or depressed by several hundred mils would include tank-to-tank engagements in mountainous terrain, precision firing in a high-rise urban setting, or the use of the tank gun as an antihelicopter weapon.

Admittedly, the gravity droop correction for elevation of the gun is small, even in the special situations listed previously; however, accumulation of small errors ultimately leads to a large error. Since it would be relatively simple to eliminate this small error by changing the M1A1 fire control algorithm, doing so may warrant consideration in the next algorithm revision.

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4. REFERENCES

Bundy, M. L. "Gun Barrel Cooling and Thermal Droop Modeling." ARL-TR-189, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, August 1993.

Held, B. J., D. W. Webb, and E. M. Schmidt. "Identification and Quantification of Sources of Occasion-to-Occasion Elevation Variability in Tank Gun Accuracy." Proceedings of the Seventh Gun Dynamics Symposium, to be published.

Hoffman, T. C. "M1A1 Tank Characteristics and Description Book." NP-86-13098-001, General Dynamics Land Systems Division, Contract DAAE07-86-C-R032, September 1987.

Schmidt, E. M. "BRL Enhanced Accuracy Gunfire Program Review." internal report for Dr. J. Frasier, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, October 1987.

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